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Overview of the photovoltaic technology status and perspective in Taiwan

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ABSTRACT

This paper investigates Taiwan's strategic promotion of the photovoltaic industry, along with the warm welcome it has extended to developments and competitive trends in global green energy technology. Through gaining a grasp of Taiwan's position as fourth globally in the photovoltaic industry and production potential, the author's main concern was with the role of the government, encouraging policies, installation incentive measures, the newest 'Renewable Energy Development Act', Science Park cluster effect strategy, initiating National Energy projects and actively promoting and improving the competitiveness of Taiwan's photovoltaic industry. The promotion of legislation and policy-orientated strategies are all a vital path to Taiwan catching up, learning and developing competitiveness in the area of science and technology related industries. Moreover, from the perspective of technological and industrial development trends, the author carried out a SWOT analysis of Taiwan's photovoltaic industry, pointing out that with the basic niche established through Taiwan's semiconductor and IC manufacturing and design, Taiwan's photovoltaic industry has the potential to take it one step further in the areas of R&D and the possibility of acquiring breakthroughs in international cooperation.

Contents

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1. Introduction

Following the global trend of low carbon economics, Taiwan too in April 2009 passed the Green Energy Industry Sunrise Program, attempting 'technological breakthrough, key investment, environmental moulding, export and import and expanding from within', these five main thrusts, to lead Taiwan on its path to become a leading country in the field of energy technology and production [1]. In fact, Taiwan's well established semiconductor and LED industries shares many similarities both in technique and management to the photovoltaic industry, as a result of which industrially Taiwan possesses the capacity for global competitiveness. The main purpose of this paper is to investigate the legislature and policy development along with the industrial strategies which the Taiwan government has pursued in order to encourage development in the photovoltaic industry and also in related R&D. Finally, from manufacturing and designing an advantageous position, consider the SWOT of Taiwan's photovoltaic development strategy.

First, this paper will take the first step in investigating the photovoltaic markets global production capacity, analyzing various governments and their approach to photovoltaic development in terms of legislature and policy incentive measures. Next, analyze the 'Renewable Energy Development Act' which Taiwan passed in 2009 and the negative and positive effects of this law on the Taiwan's photovoltaic installation and industry. Third, discuss photovoltaic installation, incentive measures and their effectiveness under the control of the Bureau of Energy at the Ministry of Economic Affairs (hereafter MOEA), along with development of cluster effects in Science Parks as part of the strategy for developing the photovoltaic industry. Fourth, analyze Taiwan's investment budget for R&D into green energy industries and the National Energy Projects initiated in 2009, leading to a discussion of the direction Taiwan's photovoltaic R&D has taken. Finally, from Taiwan's advantageous IC manufacturing and design basis, observe the strengths and weaknesses of Taiwan's competitiveness in the global photovoltaic industry and develop a constructive debate of the future need for international cooperation and possible breakthroughs in order to bring about a critical juncture in this newly emerging industry.

2. Global photovoltaic markets and production capacity

In 2007 the global photovoltaic market produced 2392 MW and Europe accounted for 69% of this. By 2008 the market produced a total of 5559 MW, of which Europe accounted for 81%, though as a result of changes in the Korean and US markets the Asian and American markets also saw a large degree of growth, with the US accounting for 6.2% of the total global market. If these figures are broken down then it becomes clear that the majority of the global market is centred in Spain, Germany, the US and Korea, these four countries, while Belgium, the Czech Republic, Japan and Portugal are currently playing catch up. Globally accumulated PV installed capacity in 2008 has reached 15 GW and European countries accounted for 65% of this, more than 9 GW, while Japan and the US followed closely in 2nd and 3rd place (with Japan accounting for 15% or 2.1 GW and the US accounting for 8% or 1.2 GW) [2]. It is estimated that by 2010 global PV needs will have reached 4900 MWp and the main markets will be in Japan, Europe and the US these developed countries (Table 1).

In 2007 the total production output value of the global PV systems market (including thin-film), was estimated at 15.4 billion US dollars, while in 2008 this total production value reached 17.2 billion US dollars, and by 2010 it is estimated that this figure will have more than doubled at 41.0 billion [3]. As for crystalline-silicon wafer-based solar cells, here too the production capacity has gradually increased from 3355 MW in 2007, to 5750 MW in 2008. In relation to global photovoltaic production capacity, upstream silicon feedstock while having experienced a lack of materials globally since 2005, yet with many new crystalline-silicon producers coming onto the market and an increase in production levels the problem of lack of crystalline-silicon materials by 2009 had already been eased [3]. In terms of midstream wafer-based solar cells and thin-film solar cells, by 2008 they had a production capacity of 1848 MW, with China becoming the greatest producer of solar cells (accounting for an estimated 29% of global production capacity) and supplier of photovoltaic products (accounting for an estimated 35% of the global market).

Taiwan's Council for Economic Planning and Development documents show [4], in 2007 Taiwan's photovoltaic industry was worth 53.5 billion TWD, a figure which had increased in 2008 to 101.1 billion TWD, with a 89% growth rate. Of the total production value of Taiwan's photovoltaic industry, 70% came from solar cells, while the rest is made up of Taiwan photovoltaic industry's most internationally competitive product, which has a production capacity of 854 MW [5] and a production value and production capacity which is 4th globally. And Taiwan's Motech is the 8th largest factory globally. In April 2009 Taiwan's Executive Yuan established the 'Green Energy Industry Sunrise Program' (Bureau of Energy, Ministry of Economic Affairs, 2009), which placed great emphasis on the importance of development in the photovoltaic industry, setting a 2015 as a goal for possessing a complete photovoltaic industry cluster in order to become the 3rd largest solar cell production country with an annual production value of 450 billion TWD.

3. Legal and policy framework

3.1. Comparison of PV policy with main countries

German renewable energy policy popularizes the notion of Germany as a place with long-standing and historical experience of such matters, where the domestic public possesses high sense of environmental protection. In particular after the German government announced a new 'Decommissioning of Nuclear Energy Act' (Geastz zur geordneten Beendigung der Kernenergienutzung zur gewerblichen Erzeugung von Elektrizitaet) in 22nd April 2002, they already announced their determination to develop policies to

Table 1
Prediction of countries' PV market needs. Unit: MWp.

No.	Country	2001–2005	2006	2007	2008	2009	2010	2001–2010
1	Japan	1400	400	600	700	900	1000	5000
2	US	400	520	520	520	520	520	3000
3	Europe	1000	200	300	400	500	600	3000
	Germany	(100)	(100)	(100)	(100)	(100)	(100)	(600)
	Italy	(50)	(50)	(50)	(50)	(50)	(50)	(300)
	Holland	(50)	(40)	(40)	(40)	(40)	(40)	(250)
	Switzerland	(800)	(210)	(210)	(210)	(210)	(210)	(1850)

Source: EPIA [2].

clean up energy and as part of this the German government became the biggest supporters of photovoltaic energy as well as successfully enabling Germany in 2007 to become the global leader in the photovoltaic market (in 2008 it was Spain). The most influential policy in all of this was the 'guaranteed advantageous feed-in-tarriffs' under the 'Renewable Energy Act' (Erneuerbare-Energien-Gesetz, EEG). This Act came into being in 2004, and enabled renewable energy sources to be purchased at a premium price by the electricity industry, moreover it offered various feed-in-tarriffs to different methods of generating photovoltaic electric power, successfully motivating Germany's domestic photovoltaic market. Moreover, Germany also invested significantly in related research, offering subsidy support measures[1] and agreeing that related grid system operators had an obligation for grid-connections. However from 2008, the purchasing price of PV generated power was adjusted in accordance with Germany's 'Renewable Energy Act' with the original annual reduction of 5% on purchasing price being gradually increased. In 2009 and 2010 for example, the purchasing price for 100 kW generated through a PV roof installation will be reduced 8%, in 2011, with an estimate that by 2012 30–100 kW of roof installation generated power will have a power price of 0.31 Euros/kWh; while panel installation systems saw a reduction of 6.5% in 2008, with an estimated reduction of 10% in 2009 and 2010. With new electricity price regulations having already come into effect on 1st January 2009, this will lead to electricity prices being reduced at a speed even greater than that of before, decreasing the incentive for residential areas to install and use household installations. In the end in order to maintain healthy domestic growth, and ensure overall control, the German Renewable Energy Act also increased market monitoring measures and requested that from 2009 all who wanted to install new PV measure systems must not only register first, but also by setting upper and lower limits on the market, and in this way the government is able to adjust the purchasing power prices proportionally along with the scale year by year. While Germany's market value is currently the second biggest globally, yet with Spain establishing subsidy support measures to a total of 500 MW, Germany hopes that in 2009 they will again be restored to first place in the photovoltaic market.

The subsidy support policies of different US states vary widely in their scope and depth as a result of vast differences in the renewable energy development aims and financial budget between them. The US National government solar power energy subsidy policy in response to the Apollo Project proposed by Barack Obama continues to move forward and while concrete specifics of subsidizing the photovoltaic industry have still not been drawn up, yet the Senate already passed an extension 30% Investment Tax Credit (ITC) for the businesses buildings and residential solar power generation systems until 2016.[2] Yet before this plan can realistically be implemented, it is of US interest for photovoltaic development policy in the main to be mutually propelled by individual state governments and legislative units, with related subsidies and support policies being relatively complex, it is possible to distinguish as: 'direct subsidy', 'establish demand goals' and 'related support subsidies' and so on [6]. Direct subsidy is mainly concerned with subsidies and investment tax credits for systems installation cost; the demand goals are Renewable Portfolio Standards (RPS) which must be established by each state individually, while some states emphasize the proportion of all generated electric power which comes from solar power[3]; 'related support subsidies' are used with the hope of removing obstacles from legislative mandates of grid-connection and power purchase. Two states which deserve particular attention are California and New Jersey, in November 2008 the Californian administration set the states 2020 RPS goal at 33%, and the state government has the power to demand electricity companies to increase the proportion of generated electricity which comes from solar power, setting the annual lowest limit at 2%, and if not reached every MWh under will be penalized to a 711 US dollar fine. New Jersey was the first state in the US to implement a policy of buying and selling solar energy.

Japan, through a strong and effective photovoltaic subsidy policy, managed to successfully develop its domestic market, but in 2006 these subsidies were all terminated. Finally in 2009 the Japanese Ministry of Economics, Trade and Industry (METI) restored the system for subsidizing residential PV systems with the aim of rapidly increasing the number of residential areas using residential PV systems.[4] From January 13th to March 31st of the same year the Japan Photovoltaic Energy Association (JPEA) organized a subsidy program aimed at encouraging more residential PV generating power installation systems, with the hope to spread the demand for photovoltaic generated electric domestically in Japan. They estimate that by the end of 2009 around 120 thousand households can make use of such subsidies. Japan also currently has a plan to implement a system to make solar generated power available for all; the solar power produced by households and enterprises could be sold with a value twice that needed to purchase the same amount of ordinary electricity; the electricity companies have guaranteed that they will purchase this energy for 10 years, providing the plan with greater policy interest and economic incentives.

The main solar energy policy promoted by the Spanish government is a 25-year long-term policy of feed-in-tarriffs, along with stipulations that architectural buildings have a responsibility to incorporate PV systems. The Spanish government previously had a more integrated photovoltaic policy which included subsidies, but that came to an end in September 2008 and while this was extended to the end of 2009, reductions in feed-in-tarriffs have already affected investments and market trust for purchasing installation systems, and by 2009 installation was limited to 500 MW, while the proportion of photovoltaic power generator being purchased at the subsidized electricity price was 1% higher than the year before, reaching a new high. In the future the Spanish government should reconsider their photovoltaic subsidy and promotional policies, EPIA in 2008's 'Global Market Outlook for Photovoltaic' until 2013 also pointed out that the outlook for Spain's market in 2009 is not likely to be able to maintain the honor of being global first.

On 28th February 2005 China announced its Renewable Energy Law which came into effect on 1st January 2006. However this law does not yet possess formulated fixed prices for purchasing so although the law requires power grid operators to purchase resources from registered renewable energy producers as well as providing grid-connection power generator services, it is still ineffective in encouraging photovoltaic installations. Another direction pursued through the aims of the 11th 5-Year Project is to promote energy economizing and reduce unnecessary waste, the 'Village Programme' is a part of this and is also related to PV

[1] After 2004 Germany made amendments to the subsidy regulations on photovoltaic system installations, that is to say they relaxed the original 'loan subsidy' limitation, increasing the amount from the previous 5–15 kW and fixing the total subsidy amount at 500,000 Euros.

[2] Each state can set its own subsidy policy: California has set aside 3 billion U.S. dollars in subsidies with the goal of possessing at least 3 GW installation by 2017.

[3] An important motivation for the current U.S. photovoltaic market is the deploying of a 'proportional renewable generated energy', which enables individual states Power Purchase Agreements and photovoltaic power exchange model to be in vogue, letting power exchange institutionalize, ensuring long term investment rewards.

[4] This system is known as 'subsidies for supporting residential photovoltaic power generator'.

system installation, as through this plan PV systems with a combined installed capacity of 300 MW have been installed [7], through this providing the power demands of around two million households, including urban roofing systems, grid-connected photovoltaic, solar energy generated power and power for remote areas. Other than this, Shenzhen and Shanghai local government have also developed plans to promote public installations and residential roof PV system installations along with ensuring that all new architecture takes responsibility for the installing of PV systems.

The development of renewable energy industries relies heavily upon the whole hearted support of governments, and the successful examples of both Germany and Japan in their experience of developing their respective photovoltaic industries clearly demonstrate this. The tools which advanced countries have chosen to use in developing their photovoltaic industries include: investing heavily in R&D prior to commercialization, during the stage of developing the market providing incentives, feed-in-tariffs and subsidy policies, along with highlighting the responsibility of power grid operators to purchase power generated from renewable energy sources, in this instance the government's sole responsibility is in reducing the gap between solar generated power prices and market power prices.

3.2. Policy of PV support in Taiwan

3.2.1. Legal framework

In response to the latest international trend towards environmental consciousness, in 2020 the Executive Yuan set the long-term goal of increasing the share of cumulative renewable energy installed capacity to 12%. At the same time, it also calls for the share of renewable electricity generation to exceed 8% by 2025.[5] As for the promotion of photovoltaic generated power, in order to achieve the photovoltaic energy installed capacity goal, the government set a goal of 21 MW by 2010 to develop the long-term goal. The Bureau of Energy at the Ministry of Economic Affairs agreed on the following goals for the development of photovoltaic domestically: first is positively promoting the installing of PV systems and exemplary programs to enable the public to become more familiar with PV systems. Second, strengthen Taiwan's off-shore island and off the track region's emergency response and preparedness against natural disasters through installing PV systems. Third, invest in R&D, developing building-integrated PV (BIPV) systems with the aim that by 2025 they can have reached 10–120,000 households, improving techniques and reducing the cost of generating energy, driving the photovoltaic industry and positively supporting the extension of exports market [8]. Moreover in terms of solar generated power the government mapped out a 7-fold strategy including broadening domestic demand; providing industries with sufficient energy; resolve the problem of a lack of poly-silicon; strengthen poly-silicon photovoltaic competitive capacity; increase integration of thin-film PV; establish a Modules Testing and Certification Service Schemes for the Asian Pacific; open the production of PV installations; indicate Taiwan power need to loosen or relax restrictions on PV grid-connection techniques. And the aim of all this is to increase the PV energy installed capacity from 21 MW in 2010 to 57 MW by 2020 [9].

In order to promote PV installations and encourage the development of renewable energy industries, on 12 June 2009 Taiwan already legislate the 'Renewable Energy Development Act'. The main content of the statute was (1) incentives for installing renewable energy power generators, however the total installation is limited to between 6.5 and 10 GW; (2) set up a fund for renewable energy, which stipulated that while operators had an obligation to handle the solar generated power, but the cost would be shared out evenly amongst grid-connection users; (3) annual feed-in-tariff determined by the council but should not be less than the average cost of domestic fossil fuel generated power; (4) power industry has grid-connections with an obligation to transmit and purchase electricity, but the cost of grid-connection is shouldered by the setting up of facilities; (5) power price subsidies, install subsidies, exemplary subsidies, importing renewable energy installation tax reductions and so on are all incentive driven policies.

As the country with the fourth largest photovoltaic output value globally, the passing of the Renewable Energy Development Act by the Legislative Yuan has a declaratory meaning for the rapid developments in Taiwan's renewable energy industries. And before this legislation was passed, the Taiwan government has already implemented incentives and subsidy policies to encourage improve PV installing capacity and industry developments. In terms of industry, the photovoltaic industry could already access related investment incentives through Article 5 'accelerated depreciation', Article 6 Paragraph 1 and Article 8 which refer to tax concessions and Article 9 with its reference to 'Custom Free' of 'The Statute for Upgrading Industries'. As for pricing subsidies, within the current 'Renewable Energy Development Act' the regulations for feed-in-tariffs are stipulated in Article 9 in which the final authority for deciding the prices for renewable energy generated power is given to various Ministries, expert and a council.[6] And before the passing of this Act, the public had worked in accordance with the contents of the Taipower Renewable Energy Purchase Principle, which involved applying to the Tai Power grid-connector for annual rights to sell their power to the grid at a price of 2 TWD per kW.

At the same time in terms of making it favourable for the public to consider installing PV systems installations, before the passing of the Renewable Energy Development Act, there was a 'Photovoltaic Generation System Installation Subsidy Guidelines' Policy administered through the Energy Bureau at the Ministry of Economic Affairs. The general population could gain subsidies of 150,000 TWD per kW, and the highest that could be gain was up to 50% of the cost of installing the power generating system.

Another aspect of this Act is the obligation of grid-connection operators. Article 8 Paragraph 1 of the Renewable Energy Development Act stipulates that, 'local power grid operators must balance grid stability and provide grid-connection for renewable energy generated power providers at the nearest possible connection, as well as to purchase and provide power in place of PV systems when the said system is shut down for repairs. This article helps in ensuring that power industry operators fulfil their grid-connection obligations as well as inciting an interest in installing PV systems in the general public.

The passing of the Taiwan Renewable Energy Development Act, on the positive side demonstrates a systematic and positive intent, yet in comparison to the likes of Germany, Japan or the US with

[5] According to the 2008 Ministry of Economic Affairs 'Sustainable Energy Policy' plans, by 2025 renewable energy should make up 8% or more of Taiwan's total electricity generation.

[6] In accordance with this regulation, immediately after the passing of the June 2009 Renewable Energy Development Act, the Bureau of Energy, Ministry of Economic Affairs set up 'the Review Board on Feed-in-Tariff for Renewable Energy Power', and a related draft was proposed; on the 24th September and 2nd October 2009 three hearings on 'the wholesale purchase rate of Renewable Energy and electricity and Calculation Formula' were held to bring together the opinions of both the industries and society for the reference of policymakers. http://www.moea-boe.gov.tw/hot/hot_02.htm [10].

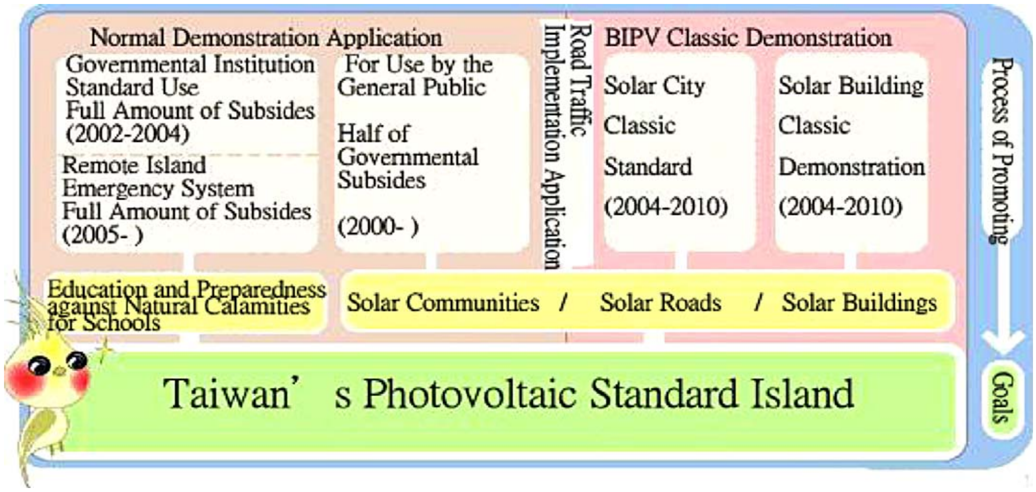


Fig. 1. Process for promoting Taiwan's photovoltaic standard island wide.*Source*: www.solarpv.org.tw, author translated from Chinese.

their feed-in-tariffs, allocation of installing subsidies, low interest financial loans and other policies, Taiwan still has room for improvement. And in relation to this policy specifically there are a few areas which need further attention:

First, from the perspective of incentives for increasing the share of cumulative renewable energy installed capacity, the renewable energy standards stipulated in Article 3 Paragraph 1 of the Renewable Energy Development Act, include solar power, biomass energy, geo-thermal energy, ocean energy, wave and tidal energy, wind energy, non-pumped storage hydro energy and refuse as resources that can be directly used or processed to produce energy and therefore can be included in the definition of renewable energy. However the definition which this Act can be applied to incorporates a number of energy forms which raise misgivings in terms of their effect on the environment and as a result, take away from the development of safe and sustainable energy forms by carving up the total incentives offered to develop energy forms which are neither safe or sustainable and in turn directly influence the future of the solar energy industry by shaking investor confidence and social incentives to install PV systems.

Second, the stipulation in Article 5 of the Renewable Energy Development Act that renewable energy responsibility for the building, maintenance and expense of connecting installed renewable energy power supplies to the main power grid is with the owner of the renewable energy power installation and not distinguishing between small and large scale installed power generators, will increase the burden of cost for the public in installing PV systems and therefore reduce the incentive for the public to install such a system. Moreover this regulation does not conform to the aim of developing the decentralization of renewable energy. After all the majority of small scale installed PV systems are non-profit in aim, and the cost of grid-connection should be the mutual responsibility of large scale installation installers and operators.

Third, the Act does not include any provision for R&D, only offering subsidies for installations and prices while leaving the industry and operators with no opportunity for improving their technological advantage. The photovoltaic industry still needs to focus more efforts on technological R&D innovation, as it is R&D which will determine the success or failure of Taiwan's photovoltaic industry in the world, in the same way that it was the key factor in Taiwan's decision to move away from its Original Equipment Manufacturing model (OEM), which impart included the Original Design Manufacturing model (ODM).

3.2.2. Installation policy of PV

To promote PV installation capacity and foster the development of Taiwan's photovoltaic industry since 2000 the Energy Committee, at the Bureau of Economic Affairs (the Energy Bureau's former name),[7] has used a series of different methods in succession including solar hot water system, PV roofing and other industry related promotional policies. Moreover beginning in the same year, the 'Subsidy Regulations on Photovoltaic Generation Demonstration System Installation'[8] was released along with other related application methods, handling guidelines for installation of PV power generating systems, encouraging domestic factories and businesses to invest in the market by using comparatively high level power supply and attracting more businesses to invest in the photovoltaic market. In March 2002 the Photovoltaic Generation Demonstration System Installation Subsidy Guidelines were modified[9] and the subsidy method was replaced by subsidy measure based upon a proportion of the total number of systems installed which in turn increases the amount of PV system installations [11]. In May 2004 the first stage of the Solar City Project to promote domestic photovoltaic city installations being constructed using a wide variety of designs and applications all focussed on showcasing the PV system [12].

In 2006 the Ministry of Economic Affairs carried out a 'photovoltaic standard system installation subsidy guideline principles',[10] which adopted incentive subsidy measures, for every kWp solar battery, the highest possible subsidy was set at 150,000 TWD, providing installation subsidies worth up to 50% of the total cost of installing the PV system to the general public in Taiwan, in order to encourage more households to use PV systems [13]. Until May 2007 the amount of PV system installations had already reached 164 units [14].

Since 2000 the Energy Bureau at the Ministry of Economic Affairs has been promoting the installation of PV systems through the following eight standard plans: 'solar roofing' (2000 until present), 'solar city' (2004–2006), 'solar power government institution building standards' (2002–2004), 'remote island emergency support system against natural disasters' (2005–2006), 'solar campus' (beginning in 2006), 'solar community', Photovoltaic Demonstration Building and 'agricultural installation support', etc. (Fig. 1). The majority of the programs mentioned

[7] July 2004 the name was changed to the Energy Bureau at the Ministry of Economic Affairs.
[8] May 2000 until March 2002.
[9] March 2002 until July 2006.
[10] From July 2006 until present.

above began in 2006 as a result of which applications for system installation subsidies also experienced a peak in this year. One instance of this was the 'solar governmental institution building standards' program used up the whole of their allocated funds, 'solar city' and 'classic PV building' come to an end in 2009 while the 'solar community' project from 2008 began a new standard program, combining both city government and residents, installing mutually beneficial group style applied system for the use of the whole community, providing more favourable support for commercial buildings. A working example of this the Ju-Lin building with its concept of a small scale energy saving community, which integrated a PV system into a residential building. Moreover, beginning in 2008 Tai-Power commissioned its Industrial Technique Research Institute Tai-Power Centre to carry out 'Photovoltaic 1st Stage Plan', in order to try and accomplish the governments mission to reach an installed capacity of 10 MW in generated systems by 2010, while also doing ground work on and preparing for the Tai-Power company plans to develop the photovoltaic industry.

At the same time, according to the conclusion of the 2009 National Energy Conference, the Ministry for Economic Affairs advocated a Project for Expanding Investment in Public Works to Revitalize the Economy, as part of which nearly half a billion TWD was invested into 4 selected standard, educational and aesthetic public buildings such as national schools or universities, social educational buildings and transport stations or recreation areas in which to demonstrate the use of large scale solar power [15].

4. Figures of Taiwan's photovoltaic status

According to resources coming from the Industrial Technical Research Institute's Photovoltaic Technology Centre, at the end of 2008 nationwide Taiwan has 384 completed PV system installations with a combined installed capacity of 4 MWp. Moreover including the 1 MWp installation in the interior of the Olympic World Stadium, Kaohsiung (Table 2 and Fig. 2), nationwide Taiwan's combined PV generated capacity has already surpassed 5 MWp [16].

In terms of 'photovoltaic systems of researching the uses', in 2008 the Atomic Energy Council Nuclear Power Research Institute began to administer the 'High Concentration PV (HCPV) Standard Plan', a system formed through 21 5 kW and 120 7.5 kW solar trackers. This plan could promote domestic upstream, midstream and downstream industries in their division of labour and early integration, while at the same time giving impetus to Taiwan's CPV industry as it matures. Another aspect of the plan is that since it touches on other areas including the manufacturing process of high efficient III/Vgroup solar cells, surveying technology, image formation and Non-Imagine Light, Fresnel Lens design, CPV cells and module manufacturing and solar tracker technology, etc., it is hoped that through an Industry-Government-Academia Cooperation method, research results can be directly streamed into domestic factories and businesses.

Since Taiwan has continuously experienced low domestic demand for solar power, following the passing of the 'Renewable Energy Development Act', it is hoped that feed-in-tarriffs, installation subsidies, public engineers obligation to install PV systems and other measures and mechanisms, will give greater motivation to see growth in the utility rate of solar power in Taiwan, while also establishing an industry value-chain, an upstream to downstream system which can provide full service and ultimately creating a turning point in the employment market. And there is already evidence of the plans success with the 2008 PV capacity growing 2.5-fold in comparison to 2007, with estimates that by 2012 the accumulated installed capacity will have reached 60 MWp.

Table 2
Taiwan PV yearly increase and annual accumulated installation capacity.

Year	Yearly increase (MW)	Total accumulated installed capacity (MW)
2003	NA	0.3
2004	0.3	0.6
2005	0.4	1.0
2006	0.4	1.4
2007	1	2.4
2008	1.6 + 1	4 + 1 (Kaohsiung Olympic Arena)
2010	NA	21 (f)
2012	NA	60 (f)

Source: The author.

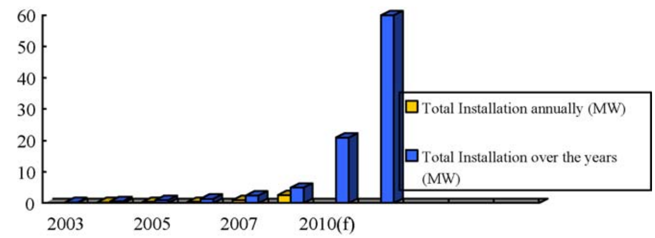


Fig. 2. Annual change in Taiwan's photovoltaic accumulated installed capacity.*Source*: The author.

5. PV industry

5.1. Strategy of PV industry

In relation to promoting the highest S&T policymaking in the development of the PV industry, in 2003 and 2004, the 23rd and 24th Science and Technology advisor board Meeting held by the Executive Yuan were aimed at discussing and analyzing the renewable energy technology industries, under the direction of the sustainable energy industrial policy, confirm the determination of the government in its commitment to promoting this field of development [17]. At the 25th Science and technology Meeting in 2005 the importance of photovoltaic technology in developing Taiwan's renewable energy industry was highlighted as key and in accordance with the Ministry of Economic Affairs 2004 'Renewable Energy Development Strategy and Action Report' confirmed Taiwan's 2010 Renewable Energy generating capacity goal at 10% [17]. In the context of these policy developments, the Executive Yuan's 2007 'Emerging Industrial Technology Strategy Review Board Meeting' for the first time was focussed on Taiwan's renewable energy development goals and strategy, including energy saving technology, renewable energy technology and subject specific discussion of foresight energy technology with photovoltaic industrial technology being a key subject for discussion. The Board made a resolution that Taiwan should make use of its semiconductor and flat panel display industrial manufacturing and control technology along with their expertise in the division of labour and experience of strategic alliances with large international factories as a dual niche to actively develop the photovoltaic industry [18].

In terms of implementing the policy, in response to Taiwan's lack the upstream crystalline-silicon production factory, the Ministry of Economic Affairs Industrial Bureau established the Taiwan Silicon Conference (TWSiCon) [19] in February 2006 to plan a strategy for developing Taiwan's key materials, supporting domestic factories and international silicon factories in discussing technology cooperation, joint ventures in establishing factories in order to bring foreign technology into domestic industries. And their successful promotion led to the first poly-silicon manufactur-

ing factory being established in 2007, providing upstream primary materials for Taiwan's photovoltaic industry, and directly integrating into the midstream solar cell manufacturing process, which in turn impacts the downstream system and application aspect, forming a production chain [20].

At the same time, the Ministry of Economic Affairs in June 2006 organised two 'photovoltaic development strategy forums' and invited industry operators, experts and related organizations, departments and businesses, to collectively discuss industrial development strategies and focus. This forum drafted 8 development strategies, including Developing the Production of Poly-Silicon Primary Materials; R&D Highly Effective and Low Cost Silicon Solar Cells; Develop New Materials for Solar Cells and Installation Production, Establish Technology of PV Modules Testing and Certification; Accelerate the Legislation Process for the Renewable Energy Development Act; Establish PV network system installation; Broaden Domestic PV System Installation Planning and increase demand in the domestic market. In August 2006 the 'Photovoltaic Industry Action Plan' was drafted and connected to the Executive Yuan's 'Industry Flagship Development Plan' for green industry items along with the '2015 Economic Development Vision Part 1 3 Year Sprint Plan (2007–2009)' as part of a plan for green industrial development [21].

In October 2007 the Ministry of Economic Affairs took another step in holding a Conference on Accelerating the Development of PV Industry and once again invited experts and related organizations, departments and businesses to jointly discuss strategies for developing the photovoltaic industry, including building an energy environment which encourages industrial development; resolve the problem of lacking poly-silicon; strengthen the competitiveness of crystallion-silicon based PV, accelerate the development of thin-film PV integration, establish a PV module testing and certification service for the Asia Pacific Region; develop PV installation production; R&D technologies of grid-connected PV systems in order to improve effectiveness of generating power [22].

5.2. Market output value

The output value of Taiwan's photovoltaic market has increased from over 200 million US dollars in 2005 to 600 million in 2006 and then 1.7 billion in 2007 and in 2008 this figure increased to 3 billion [4]. If this figure is broken down between separate categories of products, the most important output value is in solar cells which account for 70% of the total PV market output, of which the output for crystallion-silicon wafer-based solar cells made up for the greatest proportion. In the third and fourth quarters of 2008 they accounted for 700 million and 600 million US dollars, respectively and this was higher than the first and second quarters (the total output value of the first two quarters was 1.1 billion and in 2008 Taiwan remained the 4th largest solar cell producer globally, the production capacity and output value of which is respectively 1080 MW and 2.6 billion US, Fig. 3.).

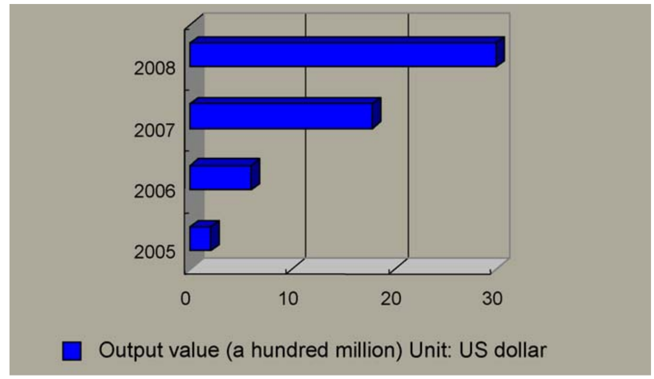


Fig. 3. Changes in Taiwan's photovoltaic output value.*Source*: The author.

Separating photovoltaic output value by technologies to analyze, despite the fact that in 2008 crystallion-silicon wafter-based solar cells remained in the mainstream, and upstream silicon material factory output also increased, yet as thin-film technology and the next-generation photovoltaic industry as a whole continues to change as a result of R&D, it is estimated that from 2009 that the proportion of the total output coming from silicon wafter-based solar cells will gradually decrease while other technologies will account for a greater proportion. In 2008 thin-film technologies and other next-generation PV technologies related businesses include: amorphous-Si and μc-Si of which there are a total of 11 factories, 5 CIGS thin filmed solar cells factories, 5 Compound semiconductor factories while there are only two factories providing materials for dye-sensitized solar cells and organic solar cells and they are the Everlight Chemical Industrial Corporation and Eternal Chemical Co., Ltd. However these types of photovoltaic compounds are in the early development stage and current production is based on available materials. Moreover, domestic factories producing photovoltaic systems have increased from 25 in 2005 to 38 in 2008 [23].

The domestic market for this technology is comparatively small, the PV industry is mainly export orientated and the government needs to consider the way they use their limited funds. In relation to R&D, they should chose to invest in developing PV techniques which can also effectively operate with subsidies and industrial development measures, to broaden the PV market domestically, and through this build a advantageous industry chain between upstream materials and downstream system services, taking a broad view of the world and achieving sustainable development through the photovoltaic industry. Therefore, the Taiwan government at this stage besides supporting technological development and installation support for industrial development, they also need to move towards constructing the right development environment for the PV industry; invest in the key points of the supply chain; entering into new developing markets; broadening demand in the domestic market; set up laws, guidelines and standards; establish testing and certification laboratories and R&D into next-generation technology [22].

5.3. Science Park of PV

Industry cluster have always been an advantage for the competitiveness of Taiwan's industries. According to the World Economics Forum, in recent years Taiwan's industry cluster development competitiveness was leading in the world.[11] Industry clusters are especially important in bringing the upstream, midstream and downstream aspects into one complete series of connections, which possess high speed communication exchange, technical support and other competitive advantages in the battle nature of the system. In particular, the comparatively long industrial chain which is a distinguishing characteristic of photovoltaic makes the industry cluster technique even more effective, similarly to the semiconductor industry, using the industry cluster method to propel the PV industry forward makes it even easier to see effective growth multiplication. The Taiwan government actively encourages 'two innovations (technological

[11] According to the 2007–2008 Global Competitiveness Report of World Economics Forum (WEF), the state of cluster development of Taiwan kept leading position in the world. Refer to WEF website: http://www.weforum.org/en/initiatives/gcp/Global%20Competitiveness%20Report/index.htm (last visit: July, 6, 2009).

Table 3
Taiwan photovoltaic industry cluster and chain distribution situation (according to product category and production areas).

Area	Technical types						
	Wafer-based PV					Thin-film PV	
	Upstream company[a]		Midstream company[a]		Downstream company[a]	Equipment corporation[a]	Midstream company[a]
	Polysilicon[b]	Solar power ingot growth, wafer slicing and wafer[b]	Combined silicon solar cell[b]	Combined silicon solar cell module[b]	Combined silicon solar cell system[b]	Thin-film solar cell production installation[b]	Thin-film solar cells and modules[b]
Hsinchu Science Park		Sino-American Silicon Products Inc., Silicon Energy, Phoenix Silicon International Corporation	DelSolar Co., GinTech Energy Corporation, Neo Solar Power Corporation, Mosel Vitelic Inc., Lof Solar Corp.		CN-J Technology Co., Ltd.	Archers System. Corp.	Sinonar Solar Corp., Compound Solar Technology Co., Ltd.
Central Taiwan Science Park	Eversol Corporation		Lof Solar Corp., Kindness Intelligence Solar	Sun Top Solar Energy Co., Ltd., Kindness Intelligence Solar		Galland Precision Machining Co., Ltd.	NextPower Technology Corp., Sunner Solar Co., Ltd.
Southern Taiwan Science Park	Taiwan Poly-Silicon Corp., TPSi	MPI Corporation, Motech Industrial Inc.	Motech Industrial Inc.	Gloria Solar International Holdings, Inc., Big Sun Energy Technology Incorporation, Kin EnerTech System Corp.	King EnerTech System Corp., Delta Electronics, Inc.	μ Technologies Corp., Metal Industries Research and Development Center	Chi Mei Energy Corp., Auria Solar Co., Ltd., Kenmos Photovoltaic Co., Ltd., Axuntek Solar Energy Co., Ltd., NanowinTechnology Co., Ltd.
Letzer Industrial Park	Top Green Technologies, Inc.	Taiwan Semiconductor Corporation, Sunrise Global Solar Energy	Sunrise Global Solar Energy, Unitech Printed Circuit Board Corp., Big Sun Energy Technology Incorporation.	PowerCom Co., Inc., Sintek Photronic Corp., Taiwan GPP Corp.			Sun Well Solar Co., Ltd.
Other areas	Muto Silicon Corporation, AE Polysilicon Corporation, Big Sun Energy Technology Incorporation, Ligitek Photovoltaic Co., Ltd.		Solargate Technology Corp., Lucky Power Technology Co., Ltd, Apollo Energy Co., Ltd., Perfect Source Tech. Corporation A2peak Power Co., Ltd.				Sun Well Solar Co., Ltd.

Source: The author.
Note: These resources do not include the CPV thin-film solar cell or other installation and inverter factories.
[a] Industry key.
[b] Product.

innovation and product innovation)' and 'two highs (high technology-intensive and high attached price), as a leading industry innovation strategy with the aim of enabling effective integration of resources. From 7th May 2001 when the Executive Yuan council passed the 'Green Silicon Island Construction Roadmap' and related policies, the government began to actively invest in developing industrial park areas and integrating the unique characteristics of local industrial development. Besides the new Hsinchu Science Park, between 2001 and 2007, the government has invested a total of 3.2 billion TWD, from north to south planning the establishing of important industrial park including Nan-Gang Software Park in the north, the Central Science Park, the Southern Science Park and the Taiwan Innovation Park in the south with the hope of giving impetus to the formation of new domestic industry clusters [24]. The government has followed this up by investing in installation funding and providing tax credit. If we consider the photovoltaic industry on its own for a moment, the majority of PV factories are situated in the Hsinchu Science Park, the Central Science Park, the Southern Science Park and Yi-Lan Letzer Industrial Park.

Before the beginning of 2009, Hsinchu Science Park had 12 factories handling PV related materials, cell modules and system manufacturing. As for the Central and Southern Science Parks along with the Letzer Industrial Park they had 8, 21 and 12 factories, respectively which handle PV materials, components, manufacturing and installation business. The programs and products which the Central and Southern Science Parks programs invest in are mainly for the constructing of a complete industrial chain for the production of crystallion-silicon solar cells and thin-film solar cells, future production capacity and accelerating next-generation thin-film technology R&D. The Central Science Park had the opportunity with NexPower Technology Corp. and Sunner Solar Co., Ltd. to add together the production total of 6 factories to become Taiwan's largest thin-film solar cell production site [6]. The Letzer Industrial Park at Yi-Lan hopes for constructing a complete photovoltaic industry supply chain began with the completion of the construction of the Shan Yang Technology factory producing poly-silicon on 26th November 2008 and now aims to make this Industrial Park the largest PV industry cluster in Taiwan, creating over 100 thousand new job opportunities [25]. For a complete picture of Taiwan's domestic photovoltaic industry clusters refer to the table below (Table 3).

6. R&D

6.1. Budget

With regards to Taiwan's PV technology R&D budget, since the beginning of the 1980s the government has channeled funds to be invested into the R&D of PV technology. And as the PV industry developed to become a key in the reusable energy technology and industrial programs, between 1999 and 2007 Taiwan invested only 20 million US dollars into PV technology R&D and applications. While the Ministry of Economic Affairs Energy Bureau invested a mere 3 million US dollars into photovoltaic R&D in 2008, a tiny sum when compared with the PV industry's 3 billion plus output value [26]. However, according to the Ministry of Economic Affair's 2008 'Sustainable Energy Policy Framework', Taiwan's energy related research funding in 2009 will almost double from around 160 million US dollars to over 300 million dollars, in order to improve the capacity of science and technology R&D.

In 2009 the total R&D budget is more than 20 million, while on the 23rd April 2009 the government announced that in order to achieve the goal set in article 3 'Green Energy Industry Rising Program' of the Six Main Newly Emerging Industries, they would set aside 600 million dollars over 5 years for technological R&D,

Table 4
A breakdown of the different categories of technologies possessed by various Taiwan-based companies.

Poly-silicon	a-Si thin-film	a-Si/μc-Si thin-film	CIGS	DSSC	III-V cell and concentrators
Motech Industrial Inc., Gintech Energy Corporation, Neo Solar Power Corporation, E-Ton Solar Tech. Corp., DelSolar Co., Ltd., Phoenix Silicon International Corporation, Mosel Vitelic Inc., Big Sun Energy Technology Incorporation, Powercom Co., Inc., Unitech Printed Circuit Board Corp., Tainergy Tech. Co., Ltd., Corum Solar Corp., Lof Solar Corp.	Sinonar Solar Corp., Green Energy Technology Inc., Ltd., NextPower Technology Corp., Sunner Solar Co., Ltd., Sun Well Solar Co., Ltd., Kenmos Photovoltaic Co. Ltd., Auria Solar Co., Ltd., Chi Mei Energy Corp., Formosun Solar Corp., NanowinTechnology Co., Ltd., Beyond PV Co., Ltd.	Sun Well Solar Co., Ltd., Auria Solar Co., Ltd., Beyond PV Co., Ltd.	Axuntek Solar Energy Co., Ltd., Ritek Corp., Achem Technology Corp., Falcon Power Co., Ltd.,	Eternal Chemical Co., Ltd.	Arima Photovoltaic & Optical Corp., Visual Photonics Epitaxy Co., Ltd., Millennium Communication Co., Ltd.

Source: PIDA [29].

Table 5
Taiwan and international solar cell technology standard comparison.

Technology item	Domestic		International	
	Laboratory stage	Production	Laboratory level	Production
Mono-silicon Solar cell efficiency	20.51% 7.14 cm^2 FZ silicon (ITRI)	14.25–17.5% 125 mm × 125 mm or 156 mm × 156 mm	24.7% 4 cm^2 FZ silicon (UNSW)	15.7–20.3% 100 mm × 100 mm HIT1 9.5% CZ 125 mm × 125 mm SunPower 21.8% FZ
Poly-silicon Solar cell efficiency	19.1% 7.14 cm^2 Poly-silicon (ITRI)	13–16.5% 125 mm × 125 mm or 156 mm × 156 mm	20.3% 1.002 cm^2 Poly-silicon (FhG-ISE)	13.35–17.7%

Source: [30].

with the hope of encouraging more than 6 billion in investment from civil society, and 800 million to bring impetus to the development of renewable energy and energy saving installations and subsidies [27]; large scale investment programs for green energy are already in line from the National Development Fund with priority investment items, however concrete programs and budget planning remain unclear, as a result of which government investments in PV R&D, promotions and subsidies trail far behind that of the governments of the world leaders in the PV field, and if we contrast the amount invested by advanced countries a proportion of their GDP, Taiwan's performance leaves even more to be desired.

At the same time, during Taiwan's 2009 National Science & Technology Conference the 'National Science and Technology Program for Energy, 2009–2013' was initiated, with a planned investment of 1 billion US dollars to encourage R&D, nearly 500 million of which was allocated to use in developing new energy technology and photovoltaic related technology was made a priority of this program. The S&T Program will strengthen research into semiconductor, solar cell, organic solar cells, HCPV system, concentrated solar thermal generation system and so on. Moreover it will give Taiwan more opportunities to take a leading role in the global PV component manufacturing and technical expertise. This program set a mid-term goal of achieving 8% organic solar cell energy capacity converter efficiency and a long-term goal of 10%. And in relation to the HCPV systems, the program aims to propel the domestic industry forward, with a goal of possessing 30% of the international market [28].

6.2. *Research of PV*

6.2.1. *Current technology of PV in Taiwan*

In terms of technology, Taiwan has only a few specialist areas in which it is currently expecting breakthrough, and generally these are trying to catch up with Germany, Japan, US technology, attaining breakthroughs in technology also comes through international cooperation such as: currently possessing comparatively specialist technological capacity is Motech and the US company NREL who are at the same stage in developing amorphous-silicon TF technology and building-integrated photovoltaic (BIPV) for which Taiwan is the lead specialist in the field.[12] Through an overall observation of Taiwan's PV technology, in terms of 'production technology' first generation combined silicon solar cell production technology has already travelled along the learning curve to maturity, the wafer and semiconductor industry possessed production technology which could be transplanted, second generation thin-film solar cells and a-Si thin-film technology were planned to a greater extend, so the companies which already work with TFT technology can easily enter into the development of thin-film solar cell technology (PIDA, 2008).

Although Taiwan R&D technology has certain advantages, however from the first, second and third generation of solar cell technology, or in terms of production technology from the upstream, to the midstream and downstream there is a great need to maintain competitiveness. According to the PIDA 2009 statistics in Table 6, Taiwan's factories currently have the capacity to produce technology, factories investing in poly-silicon and a-Si thin-film solar cells are most common, while in terms of a-Si/μc-Si thin-film, CIGS, DSSC, III-V Cell & Concentrators and other solar cell manufacturing capacity, Taiwan's factories also possess a certain degree of maturity (Table 4).

Such a manufacturing capacity demonstrates the speed with which Taiwan factories are able to transfer technologies, however, the fact is that the overall picture shows factories are still in pursuit position, with the majority of factories currently only being able to transfer technology and installations in the Turn Key style, while self-implemented research on the whole is rare, meaning that we can only expect small breakthroughs and the majority of breakthroughs are all too easily blockaded by the patents of more advanced countries such as Germany. Despite this, as a result of Taiwan's production and technological advantage in the semiconductor and electronic industries, and the fact that Taiwan's PC industry has already developed to the point where it has a completed supply chain, with all the different components, design aspects, and sub-contractor development model, there is still a chance for this to be repeated in the photovoltaic industry. In fact, the entire PV industry chain, up, mid and lower stream primary materials are not Taiwan's strength and yet with the central technology rooted in Taiwan, it can produce a cost advantage.[13]

Currently, according to the estimation of the Photovoltaic Technology Center in Industrial Technology Research Institute (ITRI), Taiwan's PV technology in water-based solar cells and energy convert efficiency still remain strong, but in terms of production capacity, the 2007 efficiency rate for production of mono-silicon was around 14.25–17.5%, while in terms of poly-silicon efficiency was slightly lower at around 13–16.5%, demonstrating a slight gap with international levels, leaving domestic production technology needing to catch up with the international standard (Table 5).

6.2.2. *Research*

According to the Executive Yuan 2007 Emerging Industrial Technology Strategy Review Board Meeting (SRB) [18], Taiwan should strengthen their research into wafter-based solar cells, a-Si/μ-Si TF solar cells, CIGS solar cells, III-V group CPV cells, etc. technology aspects. And according to the '2008 White Paper on Taiwan Industrial Technology: Innovation and Advance' [1],

[12] Lof Solar Corp. patent technology produces colourful solar cell and they have already signed a contract with the German company Centrotherm, at the beginning of next year will begin to produce unique coloured solar cells globally.

[13] Interview on Professor Lan Zong-Wen who is the director of Photovoltaic Technology Center in ITRI.

Taiwan's electronic and PV industry output value already over 1000 billion NTD, however in comparison to the world leaders, the product proportionally high while the output value is proportionally low, profit is comparatively low, showing that the domestic R&D foundation is neither deep enough nor innovative enough, depending on S&T special case investments in forthseeing R&D. Particularly in relation to photovoltaic and related solar cell and PV technology, domestic factories must discard the past method of 'high speed pursuer' and focus on a new goal of 'advance and innovation', emphasizing R&D projects differentiation and foresight. Through integrating different fields such as mechanical, control, micro/nano, micro-electrical mechanic, laser and system technology, investing in developing innovative products, and in time building newly emerging industries.

And the role of the government in investing in international scientific research cooperation and innovation is increasingly important. The white paper shows that in Taiwan's PV technology and material R&D, developing new types of thin-film materials to apply to solar cell components replacing ITO, indium tin oxide materials and developing nano-PV materials, low cost high efficiency high-temperature crytallion-silicon thin-film technology, high-density thin-film manufacturing technology and manufacturing processes, which could lead to breakthroughs in Taiwan's current technology and materials R&D.

The '2007 White Paper on Energy Technology Research and Development' also points out that the PV technology development direction in Taiwan could benefit from cooperating internationally in implementing technological R&D [31]. Besides moving towards second and third generation solar cell technology R&D, Taiwan could also develop low cost high efficiency silicon solar cells and technology research and development of wafer-based solar cells and modules, a-Si/μc-Si thin-film solar cells and modules or TFSi solar cells and modules, efficiency of PV modules and systems, compound semiconductors CPV cells, dye-sensitized solar cells, organic thin-film, inorganic thin-film and nano-materials, including international cooperation.

Silicon remains the primary material used in the current market for solar energy cells, silicon based solar cells include three main types: a-Si, mono-silicon and poly-silicon. Both mono-silicon and poly-silicon solar cells used wafer as a material base and wafer materials often have the inconvenience of being in short supply. The price of silicon used in the current market is relatively high, as a result of which the focus of R&D in this area is mainly concerned with lowering the cost of silicon, improving mono-silicon and poly-silicon solar cell efficiency along with semiconductor thin-film technology [14].

7. Taiwan photovoltaic industry's SWOT

7.1. Niche and development

In comparison to Germany, Japan or the US's long-term investment in photovoltaic technology R&D and production, Taiwan's capacity for photovoltaic R&D is weak, and in need of investing strategically in R&D; however, in the past few years through the national Turn Key mode of implementing manufacturing and producing, and because of its roots in the more stable semiconductor and panel industry, it has shown advantageous manufacturing capacity, with production capacity fourth globally.[14]

Taiwan's IC design also has a good foundation, with the 2007 MOEA graph (Table 6) showing that Taiwan's IC design, DRAM, TFT panel production are all in a leading position globally, representing

Table 6
Taiwanese products/industries in the global top three ranking, year 2007.

Ranking no. 1					Ranking no. 2					Ranking no. 3				
Item	Production value		Production volume		Item	Production value		Production volume		Item	Production value		Production volume	
10	Unit	World share	Unit	World share	10	Unit	World share	Unit	World share	6	Unit	World share	Unit	World share
Famdry	17.476	66.6%	–	–	IC design	10.970	23.9%	–	–	PCB	6.117	13.8%	43.160 (1000 yard)	4.23%
Mask ROM	351	92.9%	–	–	DRAM	7.015	22.4%	–	–	PU leather	–	–	4.474 (1000 metrictons)	32.1%
IC packaging	6.951	44.4%	–	–	WLAN*			54.597 (1000 pieces)	22%	PTA*	–	–	1.223 (1000 metrictons)	7.5%
IC testing	3.119	63.0%	–	–	OLED panel	193	33.1%			Polyester Pilamerd*	–	–	384 (1000 metrictons)	10.5%
Large size (>10 in.) TFT-LCD panel	29.827	46.4%	–	–	Small and medium size TFT-LCD panel	3.604	20.9%			Nylon fiber	–	–	1.352 K	1.5%
TN/STNLCD panel	1.555	36.9%	–	–	LED	1068	16%			Notebook PC	723	1.5%		
ED O1	1.121	38.3%	–	–	Glass fiber	787	32%							
Optical dix	2.079	65%	14.651 (million pieces)	68%	IC substrate	1.945	26.36%							
ABS*	–	–	1.319 (1000 metrictons)	20%	TPE*	–	–	774 (1000 metrictons)	11.3%					
Power wheelchair and power scooter*	–	–	210k	31.7%	Mother board (including system shipment)	178.7	2.4%	3.281 (1000 pieces)	2.2%					

Source: ITIS [33].

[14] This part of the discussion, has organised the content of interviews with Professor Huang Bing-Yun, Professor Lan Zong-Wen and National Taiwan University of Science and Technology Professor Huang and Professor Ye.

Table 7
Taiwan photovoltaic industry SWOT analysis.

Strengths	Weaknesses
Taiwan PV industry current upstream, midstream, downstream format is growing increasingly mature, possessing the advantage in internationally competitive product markets such as wafer, crystalline-silicon based solar cells and thin-film solar cells which should be invested in with expectation for the future.	Taiwan does not do a large amount of domestic market planning; it is difficult for factories to achieve mass production economy of scale or develop factory output technical experience and carry out improvements on the installation experience of local factories, on building a brand, or achieving accumulation of capital to foster R&D planning.
Domestic semiconductors technology, precision mechanic, chemical industry, electronic information and related supportive industries in Taiwan are well developed, and through the cluster effect, Taiwan has been able to develop the manufacturing production aspect of these technologies and in turn gain an advantage.	Industrial policy needs breakthrough in materials, market and Taiwan's PV industry is mainly dependent on the feedstock and market overseas, so besides accelerating the Renewable Energy Development Act legislative process and improving the strategy for broadening domestic solar energy market, developing a production chain, establishing cooperation with China for broadening Taiwan's access to primary materials and in terms of the market increasing supply and demand, are also key goals for the next stage.
Taiwan electronic technology, LED or LCD technology is plenty of talent, industry knowledge and experience, to help shorten the learning curve of production technology or R&D. Currently speaking, a PV cluster effect has already gradually formed under the guidance of government policies.	
Opportunity	**Threats**
The photovoltaic global market is rapidly growing and Taiwan currently possess R&D production manufacturing capacity with the potential to bring breakthrough.	Germany, Japan and the US having invested early in the PV industry, their technology and markets are at an advantage.
Solar cell product applications are relatively expansive including distributed generation, consumerist electronic products, communication, toys or home electronics, and developing a trend of contemporary green industry.	World governments in recent years have implemented PV price subsidies and policy reductions to enable the PV market to continue to grow.
Terminal consumerist design, fabrication and manufacturing, are also Taiwan's strengths in electronic products R&D and manufacturing processes. If willing to invest more in soft knowledge economy design in the future, there is the potential for Taiwan to develop a leading role in the global photovoltaic product market.	The rapid ascent of China's PV industry development, production capacity has already surpassed Taiwan; Korea similarly to Taiwan has moved from a foundation in semiconductors and LCD and begun to develop PV competitiveness.
The BIPV aspect of photovoltaics and buildings is also an area that Taiwan's factories currently possess an advantage and related industrial opportunities.	Currently the incentive measures and industrial incentive programs within Taiwan's Renewable Energy Development Act are controversial for not truly benefiting or nurturing the PV industry.
Taiwan will have the opportunity to invest in cooperative work related to PV fabrics.	2nd and 3rd generation solar cells R&D and manufacturing aspects, or operating in nanotechnology to develop PV products are areas which Taiwan needs to work on.

Source: The author.

Taiwan as possessing advantageous electronic industry manufacturing and design ability, especially in IC design, demonstrating that Taiwan has an advantage when it comes to performance in knowledge-intensive industry. These foundations form an important path which Taiwan must take to transform its photovoltaic industry and technology. Therefore, this paper on the basis of this will analyze the SWOT of Taiwan's photovoltaic industry, its advantages, weaknesses, opportunities and threats [32].

7.2. SWOT analysis

In terms of strengths, Taiwan's PV industry, its current upstream, midstream and downstream layout are all increasingly mature, possessing advantageous internationally competitive products including crystalline-silicon wafer, crystalline-silicon based solar cells and thin-film solar cells which should be invested in with expectation for the future. Since semiconductor technology, precision mechanic, chemical industry, electronic information and related supportive industries in Taiwan are well developed, and through the cluster effect, Taiwan has been able to develop the manufacturing production aspect of these technologies and in turn gain an advantage. At the same time, Taiwan electronic technology, LED or LCD technology is plenty of talent, industry knowledge and experience, to help shorten the learning curve of production technology or R&D. Currently speaking, a PV cluster effect has already gradually formed under the guidance of government policies (Table 7).

However in terms of weaknesses, Taiwan does not do a large amount of domestic market planning; it is difficult for factories to achieve mass production economy of scale or develop factory output technical experience and carry out improvements on the installation experience of local factories, on building a brand, or achieving accumulation of capital to foster R&D planning; therefore, industrial policy needs breakthrough in materials, market and Taiwan's PV industry is mainly dependent on the feedstock and market overseas, so besides accelerating the Renewable Energy Development Act legislative process and improving the strategy for broadening domestic solar energy market, developing a production chain, establishing cooperation with China for broadening Taiwan's access to primary materials and in terms of the market increasing supply and demand, are also key goals for the next stage.

In terms of opportunities, the photovoltaic global market is rapidly growing and Taiwan currently possess R&D production manufacturing capacity with the potential to bring breakthrough; at the same time, solar cell product applications are relatively expansive including distributed generation, consumerist electronic products, communication, toys or home electronics, and developing a trend of contemporary green industry.[15] On the other hand, terminal consumerist design, fabrication and manufacturing, are also Taiwan's strengths in electronic products

[15] PV-TRAC council proposed European Technology Platform, pointed out that in terms of the future of the photovoltaic electric power supply the advantages can be optimized, the PV system can not only be sold as a product to consumers, but also used in buildings, interior modules and the central generating installation. At the same time PV-TRAC also assess the highly competitive potential of the PV market, ensuring Europe's leading role in this high-tech industry. Refer to PV – TRAC 2006 [34].

R&D and manufacturing processes. If willing to invest more in soft knowledge economy design in the future, there is the potential for Taiwan to develop a leading role in the global photovoltaic product market. While the BIPV aspect of photovoltaics and buildings is also an area that Taiwan's factories currently possess an advantage and related industrial opportunities. Finally, Taiwan will have the opportunity to invest in cooperative work related to PV fabrics.

In terms of the threat aspect of PV, Germany, Japan and the US all invested early in the PV industry, and therefore their technology and markets are now at an advantage. World governments in recent years have implemented PV price subsidies and policy reductions to enable the PV market to continue to grow. At the same time the rapid development of China's PV industry, with production capacity having already surpassed Taiwan; Korea similarly to Taiwan has moved from a foundation in semiconductors and LCD and begun to develop PV competitiveness. Currently the incentive measures and industrial incentive programs which are part of Taiwan's Renewable Energy Development Act are controversial for not truly benefiting or nurturing the PV industry. Taiwan's renewable industries, do not focus on R&D, whereas the EU lead production in order to create innovation in R&D and it is here that these two systems show the greatest contrast. In particular with the second generation solar cells R&D and manufacturing CdTe manufacturing process and recycling breakthrough or third generation organic solar cell R&D which applies nanotechnology to open the market to new PV products, are all areas where Taiwan needs to improve and strengthen.

7.3. Discussion

It is possible to see that Taiwan's 1st Generation Solar Cell PV Industry, both production and technology are already universalized, whereas only parts of the 2nd and 3rd Generation solar cells R&D along with the whole of the production processes key technology is still lacking in Taiwan due to our need to strengthen cooperation and learning opportunities internationally. Moreover, in contrast to optionally carrying out technological R&D research and breakthrough, Taiwan, possessing limited R&D capacity pursues breakthrough to maintain the competitive edge internationally. Despite this Taiwan's markets, management, system design, demonstrate good performance in manufacturing, OEM or ODM. From one aspect these conditions have helped attract international factories to come to Taiwan to carry out manufacturing cooperation, yet from another aspect as the technology and market have gradually matured, and system design along with the development capacity of assembly products, connected to the terminal consumer flexibility of production potential, could create a turning point in Taiwan for developing globally recognized brands.

In fact, these potential paths to development are all representative of a new generation of solar cell technology in terms of breakthrough and markets, and besides the constant encouragement of Taiwan's policies, the ability to create more technological advantage incentives and manufacturing advantageous conditions for learning cooperation internationally are areas in urgent need of attention.

8. Conclusion

In conclusion, we can see that the Taiwan government is actively investing in green energy S&T industries, through a variety of policy tools they are positively encouraging the competitiveness of the PV industry. Besides the great variety of incentive measures adopted since 2004, in April and June of 2009 the passing of the Green Energy Industry Sunrise Program and Renewable Energy Development Act, respectively are a declaration for strengthening Taiwan's development goals.

However, the Taiwan Photovoltaic Industry is currently facing the contrary phenomenon to that of other leaders in PV development, industrial output value is high, domestic market is small, technology upgrading and competitiveness are contradictory in nature. While export demand for the midstream section of the production chain, solar cells and modules OEM or ODM midstream, but key technology and system service operators are of inferior quality to that of the more advanced countries. Therefore, on the one hand there is a need, through policies and incentives, to promote domestic demand, increase the capacity utilization, and in turn promote a balanced market in terms of supply and demand, accumulating operators with system ability and experience in the upstream, midstream and downstream aspects of the industry. Moreover, there is a need to strengthen international technology cooperation and competitive strategy, to increase the accumulation of technological gain through sub-contracting, developing both technology and brand name products while also mastering the future of photovoltaic technology from an end-consumer production trend perspective.

References

[1] MOEA [Department of Industrial Technology, Ministry of Economic Affairs Office]. 2008 Annual MOEA Office for Technology Development Industrial Technology White Paper: Innovation and Advances. Taipei: MEA; 2009, http://doit.moea.gov.tw/itech/preview.asp?id=93.
[2] EPIA [The European Photovoltaic Industry Association]. Global Market Outlook For Photovoltaic Until 2013. Belgium: EPIA. http://www.epia.org/index.php?eID=tx_nawsecuredl&u=0&file=fileadmin/EPIA_docs/publications/epia/Global_Market_Outlook_Until_2013.pdf&t=1243415913&hash=c7e9da1e2aeb5c862ca40a3dce08ccd8.
[3] Wang WE. 2007–2010 global photovoltaic production and market predictions. OptoLink 2008;73:17–20.
[4] CEPD [Department Planning Bureau, Council for Economic Planning and Development, Executive Yuan]. The current state and future potential of Taiwan photovoltaic industry development. Taipei: CEPD; 2009, http://www.cepd.gov.tw/dn.aspx?uid=6776.
[5] Lan CW. Taiwan photovoltaic development and technological trends. Hsinchu: Photovoltaic Technology Center, ITRI; 2009 , http://www.snec.org.cn/ppt/6-hxla/1-lcw.pdf.
[6] Wang WE, Chen WR. 2008 photovoltaic market and industry development. Taipei: PIDA; 2008.
[7] Jäger-Waldau A. PV status report 2008. Luxembourg: European Commission Joint Research Centre; 2008.
[8] Wu ZZ. Photovoltaic has arrived: the encouragement of domestic photovoltaic development. Energy Monthly 2006;6:5–7.
[9] Li QL. Good ambassadors protecting the planet – an investigation of photovoltaic industry development opportunities and policies. Taiwan Economic Research Monthly 2008;2:65–73.
[10] Bureau of Energy, Ministry of Economic Affairs. http://www.moeaboe.gov.tw/hot/hot_02.htm.
[11] Xiong GX. Taiwan photovoltaic popularization the current situation and subsidy policy. Journal of Solar Power and New Energy 2004;6:28.
[12] Xiong GX. Photovoltaic application and Taiwan's promotion situation. Special Column of Taiwan Electrical and Mechanical Engineering Services 2006;12:5–15.
[13] Quo LQ. Taiwan photovoltaic development current situation and future direction. Industrial Materials 1999;2:90–1.
[14] Chen RX. An inexhaustible supply, inexhaustible photovoltaic. Engineering 2007;8:50–60.
[15] Hong DS. Government pushed forward 5 economizing energy reducing policies. Energy Report 2009;6.
[16] Energy Report Editor Office. Ministry for Economic Affairs promote PV policy with bright results. Energy Report 2009;2:40.
[17] EY [Executive Yuan, Republic of China, Taiwan]. In: The 23rd to 25th science and technology meeting. Taipei: EY; 2003–2005, http://www.stag.gov.tw/group/application/stag/index.php.
[18] EY [Executive Yuan, Republic of China, Taiwan]. In: Executive Yuan 2007 annual production S&T strategy meeting. Taipei: EY; 2008, http://www.stag.gov.tw/group/application/stag/index.php.
[19] Chen WR. Taiwan comprehensive promotion of PV industrial development. Guan-Lian 2006;5:27–31.
[20] Chemical Monthly Editorial. Glorious solar, clear aims! – Problems of developing the photovoltaic industry. Chemical Monthly 2007;3:6–11.
[21] Zhang WZ. Taiwan's photovoltaic policy promotion situation. Industrial Materials Magazine 2007;245:124–35.
[22] Chen JD. Green industry – promoting photovoltaic industry strategic goals and concrete measures. Taiwan Economic Forum 2007;5(12):16–23.
[23] ITRI [Industrial Technology Research Institute]. ITRI electronic report. Hsinchu: ITRI; 2009, http://edm.itri.org.tw/enews/epaper/9804/a01.htm.
[24] Chen XR. The government has already established a green silicon island technological corridor niche. Council for economic planning and development

report 2007/12. http://tw.myblog.yahoo.com/jw!cJiGp3yGRkNarPTP9Wj4yvLERy1g8KmK/article?mid=1135.
[25] Wu SJ. Yi-Lan 10 key solar energy factories. United News Website 2008/11/22.
[26] Huang ZJ. From Obama's green policy discuss Taiwan consumer industry policy. Economic Daily News 2009;3:20.
[27] Lv XH. Igniting the Omen of a new energy industry. China Times E-Version; 2009/4/20. http://www.chinatimes.com.
[28] Taiwan News. National energy science and technology plan, solar power prioritized of technological development. Taiwan News 2009/6/1. http://www.etaiwannews.com/etn/news_content.php?id=975038&lang=tc_news.
[29] PIDA [Photovoltaic Industrial Development Association]. Taiwan photovoltaic industry clusters. Taipei: PIDA; 2009.
[30] Xiong GX, Zhang WZ. Taiwan PV policy promotions and vision. Taiwan Economic and Financial Monthly 2008;2:96–111.
[31] BOE [Bureau of Energy, Ministry of Economic Affairs]. White book on research and development of energy technology 2007. Taipei: BOE; 2007, http://www.moeaboe.gov.tw/Policy/PoMain.aspx?PageId=energytechwhitepaper.
[32] Weihrich H. The SWOT matrix – a tool for situational analysis. Long Range Planning 1982;15(2):54–66.
[33] ITIS [Industrial Technology Intelligence Services, Ministry of Economic Affairs]. Taiwanese products/industries in the global top three ranking. Taipei: ITIS; 2007.
[34] PV TRAC [Photovoltaic Technology Research Advisory Council]. A vision for photovoltaic. Belgium: European Communities; 2006, http://ec.europa.eu/research/energy/pdf/vision-report-final.pdf.